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GROUND ROUGHNESS EFFECTS FOR
FALLOUT-CONTAMINATED TERRAIN:
COMPARISON OF MEASUREMENTS AND CALCULATIONS

10 by
J. M. Ferguson

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ADMINISTRATIVE INFORMATION

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ABSTRACT

The effect of ground roughness on the radiation field above fallout-contaminated ground is studied. At past weapons tests, the dose rate over fallout-contaminated ground, was been measured as a function of height and angle. These measurements are compared with calculations of the same quantities for 1.12-hr fission products uniformly distributed on a smooth plane. None of the experiments is detailed enough to lead to firm conclusions about the ground roughness effect. However, the data indicate that the ground roughness effect can be simulated by assuming that the fallout is buried under a thin layer of material. For desert terrain this thickness of material is equivalent to about 25 ± 10 ft of air. At 3 ft above the ground this corresponds to a reduction in dose rate by a factor of 0.6 to 0.7, compared to what would be received over a smooth plane.

SUMMARY

The Problem:

To calculate the dose rate at a point a few feet above ground
uniformly contaminated with fallout. In the ideal case of perfectly
smooth ground, most of the radiation comes from large distances. Air
attenuation determines the maximum distances of importance and, since
the mean-free-path of gamma rays in air is of the order of hundreds of
feet, these distances are large. Consequently, much of the radiation
reaching the detector travels at a grazing angle to the ground. In
this situation, irregularities of the ground can significantly modify
the field, since they will shield a detector from gamma rays traveling
at low angles with respect to the ground. This ground roughness will
affect dose versus height or dose versus angle observed in a fallout
field. The deviation of these quantities from what is predicted for a
smooth plane source is a measure of the effect of ground roughness.
One way of taking this effect into account in calculations is to assume
that the fallout is buried under a thin layer of material. Gamma rays
leaving the source at low angles with respect to the ground will be
highly attenuated by this layer, and the effect should be similar to
that of ground roughness.

The Findings:

In this report we compare dose versus height and dose versus angle
measurements made at field tests with what is calculated for an infinite
plane source of 1.12-hr fission products.[1] We take the ground roughness
into account in the calculations by assuming that there is a layer of
material equivalent to τ feet of air between the source and detector.
For each set of experimental data the value of τ which best matches the
calculations to the data is found. In this manner it is found that,
for experiments performed over ordinary desert terrain, τ has the value
of 25 + 10 ft of air. For the one experiment over plowed ground, τ is
about 60 ft. It is concluded that the concept of simulating the ground
roughness by an equivalent layer of material τ should be adequate for
most applications. That is, modifications of the magnitude and angular
distribution of the dose rate by ground roughness are adequately
simulated by putting a layer of material, τ, into the calculations for

ABSTRACT

The effect of ground roughness on the radiation field above fallout-contaminated ground is studied. At past weapons tests, the dose rate over fallout-contaminated ground, has been measured as a function of height and angle. These measurements are compared with calculations of the same quantities for 1.12-hr fission products uniformly distributed on a smooth plane. None of the experiments is detailed enough to lead to firm conclusions about the ground roughness effect. However, the data indicate that the ground roughness effect can be simulated by assuming that the fallout is buried under a thin layer of material. For desert terrain this thickness of material is equivalent to about 25 ± 10 ft of air. At 3 ft above the ground this corresponds to a reduction in dose rate by a factor of 0.6 to 0.7, compared to what would be received over a smooth plane.

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a smooth plane source. Some of the data indicate that τ may well depend as much on variations in the gamma-ray spectrum as on the nature of the ground. However, the experimental work to date is not detailed enough to lead to firm conclusions about how the ground roughness effect varies with type of surface or source energy spectrum.

INTRODUCTION

One of the factors that determines the dose rate over fallout-contaminated terrain is the roughness of the surface of the ground. The literature on weapons effects contains a number of measurements which are sensitive to this parameter. In this report we compare these measurements to calculations of the fallout radiation field in order to learn more about ground roughness effects.

To a first approximation, fallout can be treated like a plane isotropic source on top of a smooth ground-air interface. The dose rate inside a structure is estimated by calculating the attenuation and scattering of the ground and air and material in the structure, using the plane isotropic source as input data. The basic calculations and methods of attack are presented in Spencer's monograph, "Structure Shielding Against Fallout Radiation from Nuclear Weapons."[1]

As Spencer points out, fallout is not accurately represented as an unshielded source on top of the ground, even for reasonably smooth ground. The ground partially shields the source. This is the so-called ground roughness effect. This shielding is most important for gamma rays traveling almost parallel to the ground, and these gammas contribute most of the dose at heights of a few feet.

One method of correcting for ground roughness is to assume that the fallout is buried under a thin layer of material. In Spencer's work[1] this layer presents itself as an equivalent layer of air thick enough to have the same attenuation properties as the layer of material. Thus, gamma rays reaching a height d ft above the ground are attenuated by an amount of material equivalent to d + τ ft of air, where τ is the thickness of air needed to simulate the ground roughness effect. In lieu of a detailed investigation of the ground roughness effect, Spencer tentatively adopts 40 ft of air as a typical value of τ. This corresponds to about 1 cm of soil, for a soil density of 1.5 gms/cm^3.

Ground roughness effects have been studied at the Nevada Test Site. Measurements were made by five different field projects, on four different shots, over different ground, and at different times after detonation. Although each group used a different method to study the effects, one can derive a value of τ from each set of data. Because of the different experimental approaches, some of the data are more sensitive to ground roughness than others and, hence, should be given more weight in drawing conclusions.

In this report we will review the experimental results to see if the data are consistent with the concept of an equivalent layer of air, and what values of τ fit the data.

In each case the field data are compared with predictions based on Spencer's monograph. We will try his results, for the appropriate conditions, using different values of τ to find the best fit with the data. It is possible to make more specific calculations. However, we are more interested in seeing to what extent the different ground roughness effects can be reproduced by the same general calculation.

Even if the method works well, we expect only approximate agreement. The initial source conditions are not the same as those in the calculations, nor are they the same from experiment to experiment. Spencer assumes a 1.12-hr fission product gamma spectrum, while the measurements were made at times ranging from 54 hr to 9 days after the shot. Over this time the energy spectrum changes considerably. Also, the types of measurements made and the types of geometry studied vary from case to case, so experimental errors and calculational approximations affect each comparison differently.

For the proper choice of equivalent air thickness, τ, the calculation reproduces the experimental data quite adequately. The value of τ varies somewhat from case to case, as would be expected, since the experiments were done over different terrain. No careful characterization of the nature of the ground roughness was made in any of the experiments. That is, there is no quantitative description of how the ground physically differs from a smooth plane. In fact, there seems to be no established criteria for defining the roughness of a given piece of ground. Hence, no conclusions are drawn about the significance of the variation of τ from case to case.

CALCULATIONAL RESULTS

Since all the calculational results quoted in this report are taken from Reference 1, we briefly review the methods used to make the calculations shown in this reference.

The case in which we are interested is the dose rate above uniformly contaminated ground. For this case Spencer uses a moments method calculation for a plane isotropic source in an infinite air medium. It is assumed that, except for density, soil is just like air. This should be a good assumption for low-Z materials. Also, it is assumed that the density interface does not alter the infinite plane results too much. This should be a good assumption except for grazing angles with respect to the ground.

Thus, all the calculational curves used throughout this report refer to calculations in an infinite medium. The output of the calculations is presented in Reference 1 in the form of graphs of dose per steradian as a function of angle, for various detector heights (Fig. 26.1 of Reference 1), and also curves of 4π dose versus height (Fig. 28.2 of Reference 1). An effective layer of material may be "inserted" between source and detector merely by choosing the appropriate detector height when reading numbers from the curves. The extra height, τ, corresponds to a layer of material with the same mass thickness as τ ft of air.

EXPERIMENTAL RESULTS AND COMPARISON WITH THEORY

Each experiment is considered separately. This is because each was done for different terrain, so they are not necessarily comparable. Also, the method of comparison changes from case to case.

Operation Teapot, Project 2.3b[2]

The gamma-ray spectrum at a point 105 cm above the ground was measured as a function of angle from the vertical. The measurements were made 9 days after the shot. The angular resolution of the apparatus was 3 deg.

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Much data analysis is given in the report. By computing the attenuation of different energy groups as a function of angle, it was determined that the fallout was effectively buried under about 0.45 gms/cm^2 of material. This corresponds to a τ of about 11 ft of air.

In addition to the above analysis, the gamma-ray spectra were integrated to give relative dose per steradian, as a function of angle from the vertical. These data may be compared directly with Spencer's calculations of dose versus angle, for air layers of various thicknesses. Figure 1 shows the experimental dose-per-solid-angle angular distribution, 3.5 ft above the ground, and Spencer's angular distribution (Fig. 26.1 of Reference 1) for a thickness of material equivalent to 16.5 ft of air. (This corresponds to a τ of about 13 ft of air.) The curves are normalized to give equal total doses from below the horizon. The $\cos \theta = -1$ point corresponds to the detector looking straight up; $\cos \theta = 0$, to looking at the horizon; and $\cos \theta = +1$, to looking straight down.

The curves agree very well. The calculational curve peaks more sharply just below the horizon. This is to be expected, because the experimental appratus had an angular resolution of about 3 deg and would smear out a sharp peak. The only significant disagreement is for the skyshine. At small angles the experimental curve is about a factor of 2 higher than the calculated one. This effect is not accounted for by the angular resolution of the apparatus or the differences in the input energy spectra. However, the skyshine contributes a small fraction of the dose, and is important only in special shielding situations.

To summarize, both the analysis given in Reference 2 and comparison with Spencer's calculations give about 13 ft of air for τ, the layer of material under which the fallout is effectively buried. The calculated angular distribution agrees reasonably well with the experimental one, except that the experimental one has a larger contribution from air-scattered radiation.

Operation Plumbbob, Project 32.4[3]

This project used a different approach to study ground roughness. Dose rate versus height above fallout-contaminated ground was measured for two different shots.

The first set of data is different from the others discussed here in that a comparison can be made between absolute source strengths and absolute dose rates. In the others, the interpretation is based on the variation of relative dose rate with angle or height.

Fifty-four hours after the shot, dose rate versus height was measured to 1660 ft above the ground. Earlier, all the activity from a 2.68-sq ft fallout collector in the same area had been flown back to NRDL, and its gamma-ray spectrum was determined at the same time the dose rate versus height was being measured.

Reference 3 then uses the spectral data, in photons per sec per Mev per square foot, to compute dose rate versus height, assuming no ground roughness effect. The calculations and measurements from Reference 3, and Spencer's curves for different values of τ (Fig. 28.2 of Reference 1) are shown in Fig. 2. Spencer's values of d, the height above the ground, were multiplied by 1.17 to correct for the lower air density at the Nevada Test Site. They were normalized to give the same dose rate at the surface, for zero ground roughness, as the calculation based on the spectral measurement.

Note that at higher altitudes Spencer's curve (dashed line) does not agree well with either the experimental points or with the solid curve calculated from the spectral data. This is because the 1.12-hr fission product spectrum used by Spencer is different from the 54-hr fallout spectrum used by Schuert. Over the first 400 ft, however, the curves agree within 10 percent. The agreement is excellent between the measurements and the curve calculated from the spectrum. We will discuss effects of changes in the spectrum later.

We may use either set of calculations to get a value of τ. In each case the calculated curve is shifted to the left by 1.17 τ ft. (The factor 1.17 corrects for the difference in air densities at the Nevada Test Site compared to standard temperature and pressure.) Matching the curves near the surface, Schuert's calculation gives $\tau \simeq 20$ ft, and Spencer's calculation gives $\tau \simeq 37$ ft. These correspond to the lower solid curve and the lower dashed curve in Fig. 2.

Reference 3 also gives some dose information for the same area, but for 14 hr after the shot. A comparison is made with dose rate calculated on the basis of Mo^{99} in the fallout, and assuming an unfractionated fission-product sample. The method did not appear to be accurate enough to distinguish ground roughness effects from the error in estimating the source strength, so the 14 hr data are not considered here.

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The second experiment by Project 32.4, Operation Plumbbob, was a measurement of dose rate versus height, up to a height of 60 ft. These data were taken at a different shot, over different ground, and at a different time after shot from the first experiment. The data were taken 5 days after the shot. No measurements of activity per square foot were made, so the data cannot be related as in the first experiment. A value for τ can be obtained from the shape of the curve. We include the results for completeness. However, the lack of absolute measurement of the source strength, together with the lack of fit of the shapes of the curves in the previous experiment, eliminates the possibility of drawing firm conclusions from these data. The experimental curve is shown in Fig. 3, together with curves for various values of τ calculated from Spencer. Spencer's curves are normalized to the data at $d = 60$ ft, where the ground roughness effect should be small. These data give a τ of 25 ft of air. As the graph shows, the small difference in the shapes and the scatter in experimental points actually gives very little to choose from the the range between $\tau = 15$ ft and $\tau = 35$ ft. The value 25 ft gives the best fit close to the ground, where the dose is most sensitive to ground roughness. As stated above, however, these particular data are not complete or sensitive enough to allow us to draw any conclusions about ground roughness effects.

Operation Jangle: NRDL-TR-108[4]

This experiment uses still another way of studying ground roughness effects. Dose rate versus height was measured over an area of contaminated ground. A square area, 32 ft on a side, was then cleared of fallout, and dose rate versus height was measured over the cleared area. Making the measurement over a cleared area accentuates the ground roughness effect, because all the direct radiation reaching the detector travels at grazing angles with respect to the ground.

Ksanda, et al., give measured dose versus height over the cleared area*normalized to the dose 3 ft above the uncleared ground.[4] Spencer gives an approximate expression (equation 30.4 of Reference 1) for the relative dose over a cleared circular area relative to the dose over a cleared area with no ground roughness:

$$D/D_o \simeq D(d+\tau/1-\omega)/D_o,$$

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*The data used in Reference 4 were taken from the work reported in WT 400, Operation Jangle, Project 6.2, Protection and Decontamination of Land Targets and Vehicles.

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where D and D_0 are the doses under the stated conditions, d is the
height in feet, τ the effective air layer resulting from ground rough-
ness, and ω the solid angle subtended at the detector by the cleared
area. $D(x)$ refers to Spencer's value for the dose times x feet of air
above a contaminated plane. To normalize this quantity to the relative
dose presented by Ksanda, we multiply

$$D(d+\tau/1-\omega)/D_0 \quad \text{by} \quad D_0/D(d+\tau).$$

Both ratios can be obtained from Spencer's curves. The results,
together with the experimental data, are shown in Fig. 4. Although
none of the calculated curves fits the data for all height, the
$\tau = 35$ ft calculation gives the best fit over the range. Agreement is
within 10 percent for all heights. It is not surprising that the fit
is not as good as for other types of analysis, since the expression for
a cleared area $D \sim D(d+\tau/1-\omega)$ involves approximations not needed for the
infinite plane source case. Also, the expression is derived for a
circular area, rather than the square one considered here. We conclude
that this set of data indicates $\tau \sim 35$ ft of air.

Operation Sunbeam, Project 2.14[5]

These ground roughness data again consist of dose versus height
measurements over a cleared area. The dose was measured relative to
the dose 3 ft above the ground in the same part of the fallout field,
but away from the clearing. The cleared area was circular with a
radius of 10 ft. The dose versus height was computed as before; it is
shown with the data in Fig. 5. The best fit is for $\tau \sim 15$ ft of air.
Although the fit is not as good as in Fig. 4, the calculated curve
fits the data to within 10 percent over the entire range of heights.
Note that in this case and the previous figure, the calculations need
not be normalized to the data, so the magnitudes of the curves as well
as the shapes are significant.

Operation Sunbeam, CEP 62.81[6]

In this experiment ground roughness was studied by measuring the
gamma-ray intensity and energy as a function of angle from the
vertical. Thus the data are similar to those in Reference 2. The

experiment differs from those considered previously in that three different types of terrain were studied: a flat dry lake bed, a rough desert terrain, and a plowed field. The rough desert terrain probably most closely resembles the terrain in the other experiments. The dry lake bed would be expected to be smoother, and the plowed field rougher.

The final report is not yet available. The discussion here is based on the interim report, so the results are tentative. The relative dose per steradian versus angle was obtained as a function of angle from the vertical.

The dose versus angle curves are shown in Figs. 6, 7, and 8, together with calculated dose versus angle curves for different values of τ, the equivalent thickness of air. The data for the dry lake bed and the plowed ground were obtained from 1 to 2 days after the shot, and the data on the rough desert data were obtained 5 days after the shot. Both the data and the calculated curves were taken directly from Reference 6. Both the dry lake bed and the rough desert terrain data indicate a τ of about 33 ft. A correction of the data for the angular resolution of the apparatus would sharpen the peaks and give a somewhat smaller value of τ. However, it is doubtful that τ would change substantially since the fit is quite good over all angles.

The data for the plowed field, Fig. 8, differ significantly in shape. The calculated curve is for $\tau = 66$ ft of air, a factor of 2 bigger than anything obtained previously. This, of course, is not surprising, since the ground was deliberately roughened. It is perhaps surprising that τ was not even larger. An inset of a typical ground profile is included in Fig. 8; this also was taken directly from Reference 6.

CONCLUSIONS

The results of each experiment are summarized in Table 1. The "errors" for τ were assigned by the author and simply represent the range over which the calculated and experimental curves give reasonable

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agreement. These errors do not represent experimental errors in the quantities actually measured.

TABLE 1

Ground Roughness Factors Obtained by Comparison of
Reference 1 Calculations with Experiments

Ref.	Type of Experiment	Equivalent Air Thickness in feet, τ	Ground Roughness Factor	Terrain
2	Angular Distribution	13 ± 5	0.71	Desert
3	Dose versus Height	37 ± 15	0.54	Desert
4	Cleared Area	35 ± 10	0.55	Desert
5	Cleared Area	15 ± 10	0.69	Desert
6	Angular Distribution	30 ± 10	0.58	Desert
6	Angular Distribution	30 ± 10	0.58	Dry Lake Bed
6	Angular Distribution	63 ± 20	0.44	Plowed Ground

The values of τ are used to calculate the ratio of the dose at 3 ft over the rough ground to what would be observed at 3 ft over a smooth plane, with the same contamination. This ratio is defined as the ground roughness factor, and is obtained from Fig. 28.2 of Reference 1 for the appropriate τ. It varies from 0.54 to 0.71 for "typical desert terrain" and goes down to 0.44 for plowed ground.

Except for the plowed field, all the results can be described by using $\tau = 25 \pm 10$ ft of air-equivalent material. This can be considered good agreement, in view of the variation in time after shot, ground areas used, and different methods of collecting and analyzing the data. All the terrain for these measurements, except the lake bed, would be described qualitatively the same way. It is typical desert terrain with

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a little sage covering, and an occasional Joshua tree. However, it is known that the soil density, rock content, and flatness vary from area to area, so the terrains are not identical. The value of $\tau \sim$ 30 ft for the dry flat bed seems large because it looks very flat compared to other areas. Reference 6 suggests that the many cracks in the surface may account for the roughness effect.

It may well be that the variations in τ are due to the differences in source spectra as much as they are due to differences in ground roughness. The work in Reference 3 indicates that for deep layers of air spectral differences change the calculated dose by a factor of 2 to 5 from that calculated for 1.12-hr fission products. This being the case, it seems reasonable that the value of τ for a given plot of ground will vary with time after shot. Since no careful investigation of the ground roughness effect for known sources of different energies has been made, we will not pursue the question further.

The concept of using an equivalent layer of material to simulate the ground roughness is probably best tested by Mather's analysis.[2] He shows that the angular distribution of direct radiation of various energies can be reproduced fairly well by putting in a layer of air-equivalent material. This indicates that the approximation should be adequate for most shielding applications. There is quite a difference between the calculated and predicted skyshine, however, and this problem needs further consideration.

Of course, all the data discussed here are for desert terrain, and leave unanswered the question of what happens for other types of terrain. Also, it should be kept in mind that the ground roughness factor presented here was inferred from the way dose varies with height or angle, rather than absolute measurements of dose rate and source strength. It is quite possible that the shapes of these curves can be represented by one value of τ, but that the actual reduction in dose rate will be equivalent to quite a different value of τ.
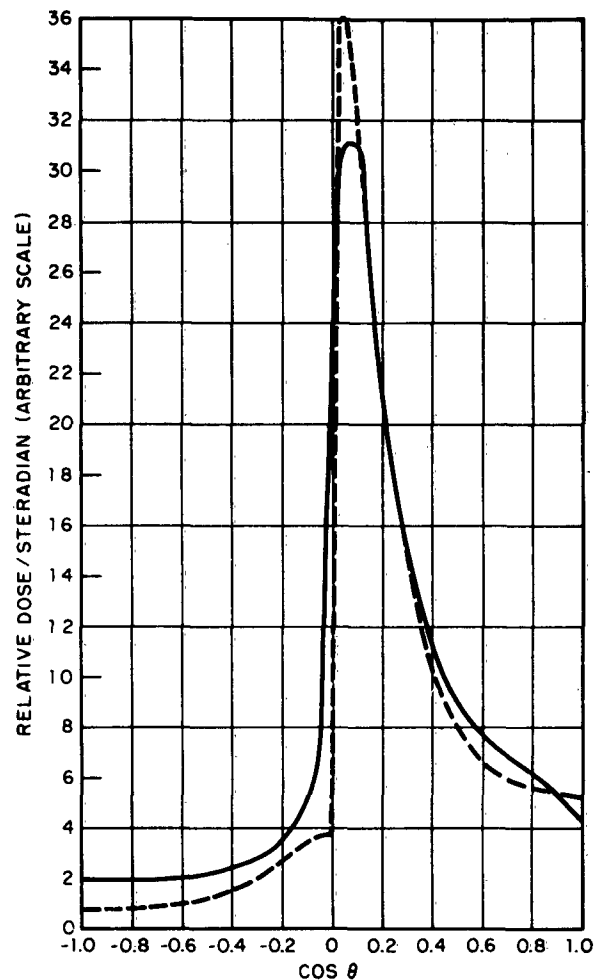
Fig. 1 Comparison of angular distribution of dose/steradian obtained from Mather's data[2] and from Spencer's calculations.[1] The solid line (Mather) is computed from spectrum vs. angle measurements at 3.5 ft above the ground.[2] The dashed curve (Spencer) is the dose/steradian calculated for a height of 16.5 ft. In the notation of the text, this corresponds to a τ of 13 ft of air. The angle θ is defined so that for $\theta = 0$ the detector looks straight down at the ground. The curves are normalized so that the total doses from below the horizon (cos $\theta > 0$) are equal.

11
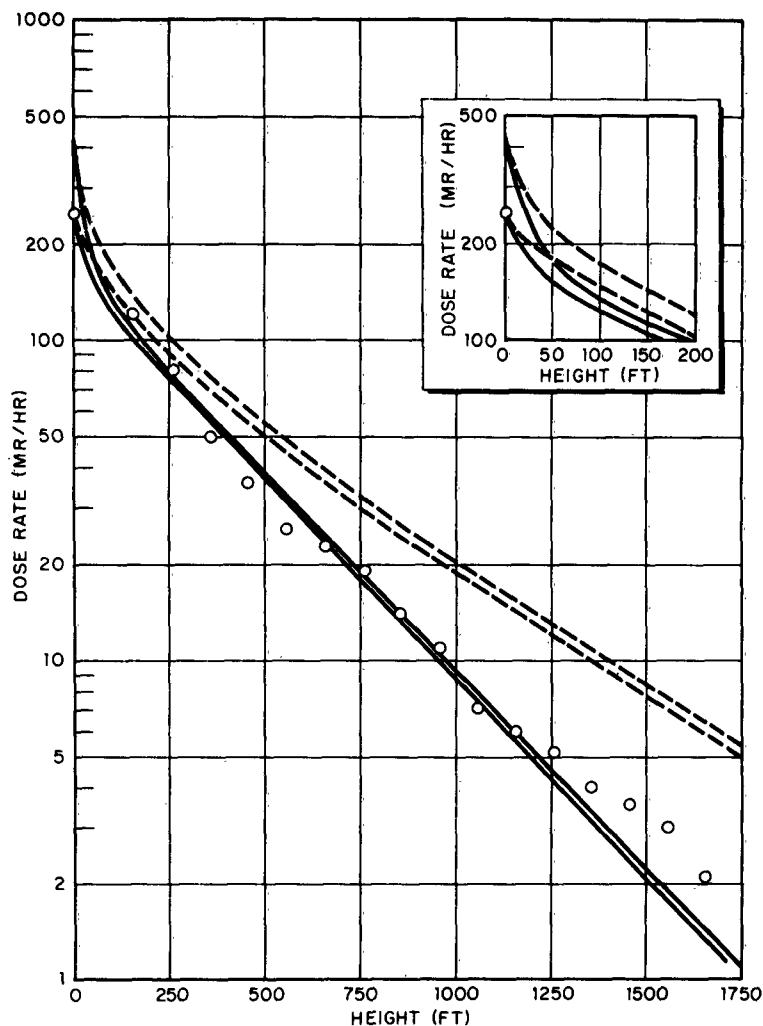
Fig. 2 Comparison of calculated and measured dose rate vs. height
curves. The open circles are measured dose rates above a fallout field,[3]
54-hr after the shot. The upper solid curve is the dose rate calculated
from measurements of the gamma-ray energy spectrum and intensity of fall-
out collected from the same area in which the measurements were made.
The lower solid curve is the same calculations shifted so as to corres-
pond to ground roughness equivalent to 20 ft of air. The upper dashed
curve is Spencer's dose vs. height (corrected for air density) curve for
1.12-hr fission products, and no ground roughness. It is normalized to
Schuert's calculation at zero height. The lower dashed curve is Spencer's
calculation adjusted to a ground roughness effect equivalent to $\tau = 37$ ft
of air.

12
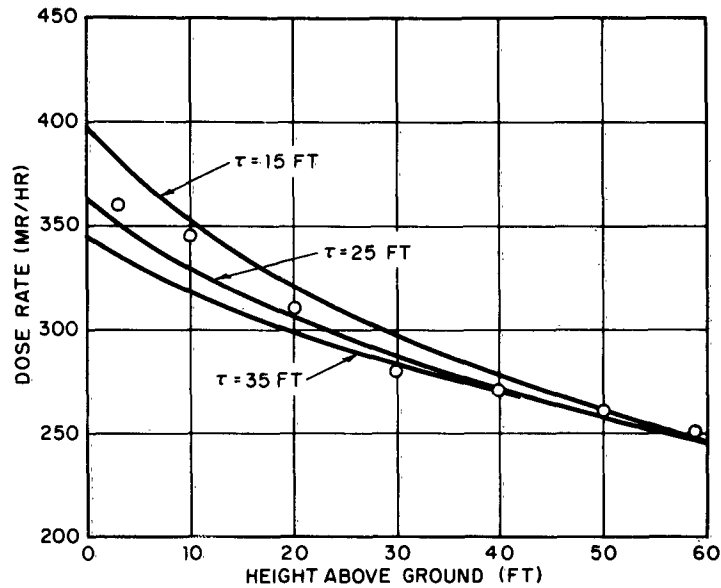
Fig. 3 Comparison of calculated and measured dose vs. height curves.
The open circles are measurements from Reference 3, and the solid curves
are calculations from Reference 1, using the equivalent air thicknesses
τ indicated in the figure. The calculated curves were normalized to the
data at 60 ft above the ground, where ground roughness effects should be
small. Also, the heights used in the calculations were adjusted to
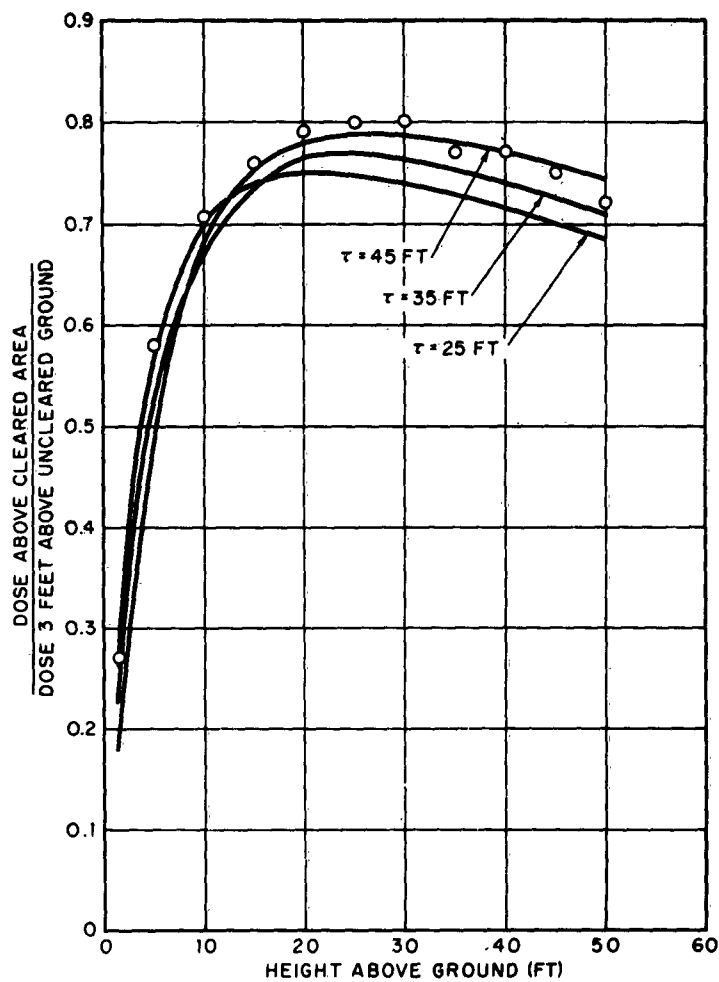correct for the air density at the Nevada Test Site.

Fig. 4 Comparison of calculated and measured dose vs. height over a
cleared area. The ordinate is the ratio of dose over the center of a
square area 32 ft on a side, cleared of contamination, to the dose 3 ft
above an uncleared area with the same contamination and ground rough-
ness. The open circles are measurements reported in Reference 4, and
the solid lines are calculated from Reference 1, using the indicated
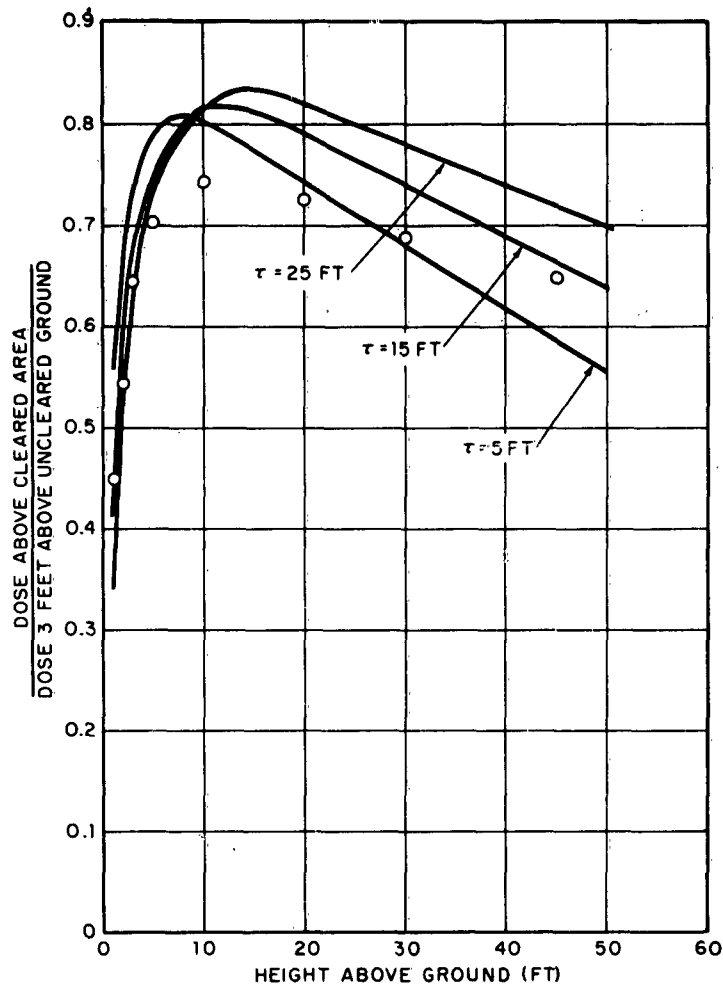values of the equivalent air thickness, τ.

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Fig. 5 Comparison of calculated and measured dose vs. height over a
cleared area. The ordinate is the ratio of dose over the center of a
cleared circular area 10 ft in radius, to the dose 3 ft above an
uncleared area in the same vicinity. The open circles are measurements
reported in Reference 5, and the solid lines are calculated from
Reference 1, using the indicated values of the equivalent air thickness,
τ.

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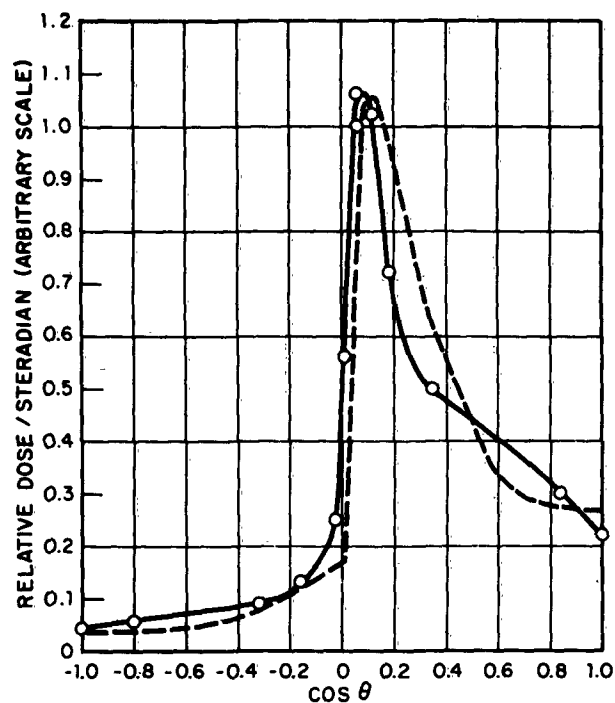
Fig. 6 Comparison of calculated and measured angular distribution of dose/steradian over a dry lake bed. The angle is so defined that $\cos\theta = +1$ corresponds to the detector looking straight down at the ground. The open circles and solid line are measurements over a dry lake bed,[6] and the dashed curve is the calculated angular distribution given in Fig. 26.1 of Reference 1, for an equivalent air thickness, τ, of 30 ft.
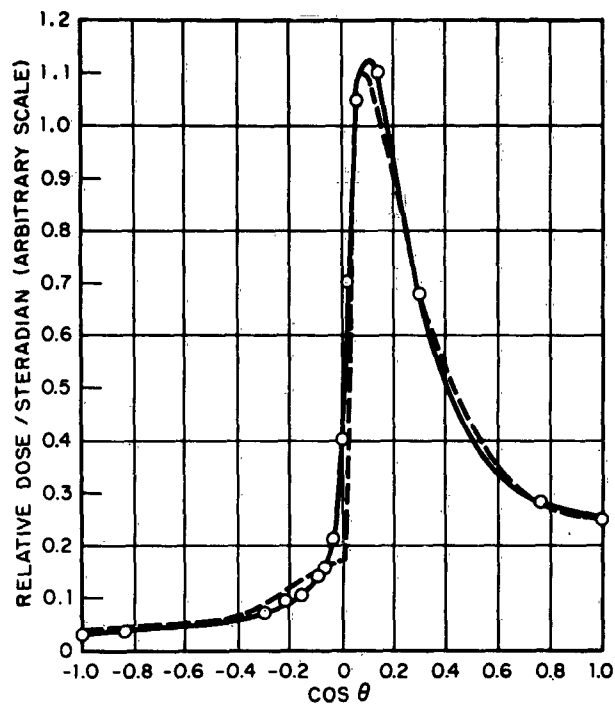
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Fig. 7 Comparison of calculated and measured angular distribution of dose/steradian over rough desert terrain. The angle is so defined that $\cos\theta = +1$ corresponds to the detector looking straight down at the ground. The open circles and solid line are measurements over rough desert terrain,[6] and the dashed curve is the calculated angular distribution given in Fig. 26.1 of Reference 1, for an equivalent air thickness, τ, of 30 ft.
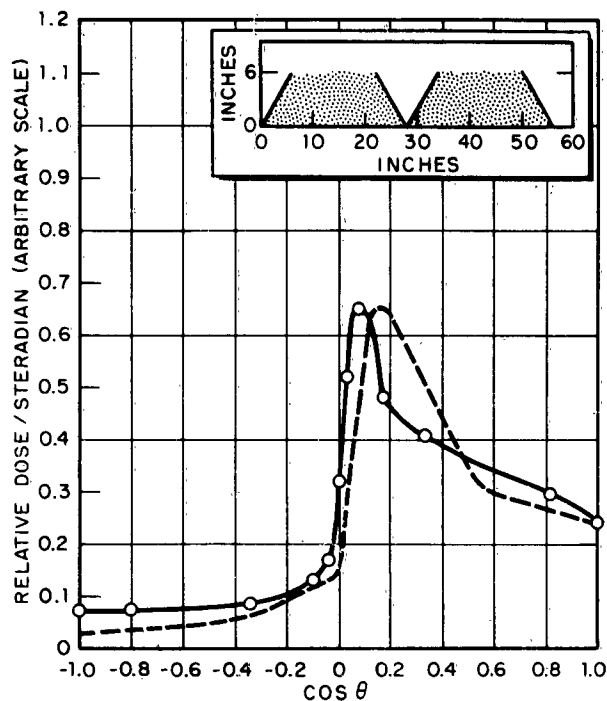
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Fig. 8 Comparison of calculated and measured angular distribution of dose/steradian over plowed ground. The angle is so defined that $\cos\theta = +1$ corresponds to the detector looking straight down at the ground. The open circles and solid line are measurements over plowed ground.[6] The inset shows a typical profile of the ground. The dashed curve is the calculated angular distribution given in Fig. 26.1 of Reference 1, for an equivalent air thickness, τ, of 33 ft.

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1	Chief, Bureau of Yards and Docks (Code C-400)
1	Chief of Naval Operations (Op-07T)
2	Chief of Naval Operations (Op-03EG)
1	Chief of Naval Research (Code 104)
1	Commander, New York Naval Shipyard (Material Lab.)
1	Director, Naval Research Laboratory (Code 2021)
1	Office of Naval Research (Code 735)
1	Office of Naval Research Branch Office, SF
1	CO, U. S. Naval Civil Engineering Laboratory
1	U. S. Naval School (CEC Officers)
1	Commander, Naval Air Material Center, Philadelphia
1	CO, Naval Air Development Center
1	CO, Naval Engineering Experiment Station
1	U. S. Naval Postgraduate School, Monterey
1	Commander, Naval Ordnance Laboratory, Silver Spring
1	Commander, Naval Ordnance Test Station
1	Director, Naval Weapons Laboratory, Dahlgren
1	CO, Naval Nuclear Ordnance Evaluation Unit
1	CO, Nuclear Weapons Training Center, Pacific
1	CO, Nuclear Weapons Training Center, Atlantic
1	CO, Naval Training Devices Center
1	Director, Institute of Naval Studies, Newport
1	Commandant of the Marine Corps (A03H)
1	Commandant, Marine Corps Schools, Quantico (CMCLFDA)
1	Director, Landing Force Development Center

ARMY

1	Chief of Research and Development (Atomic Division)
1	Chief of Research and Development (Life Science Division)
1	Deputy Chief of Staff for Military Operations (CBR)

1	Chief of Engineers (ENGMC-EB)
1	Chief of Engineers (ENGMC-DE)
1	Chief of Engineers (ENGCW)
1	CG, Army Materiel Command (AMCRD-DE-NE)
1	Chief of Transportation
1	CG, Ballistic Research Laboratories
1	CG, USA CBR Agency
1	CO, Fort McClellan, Alabama
1	Commandant, Chemical Corps Schools (Library)
1	Chemical Committee, Army Infantry School, Fort Benning
1	CG, CBR Combat Developments Agency
1	CO, Chemical Research and Development Laboratories
1	Commander, Chemical Corps Nuclear Defense Laboratory
1	CG, Aberdeen Proving Ground
1	Director, Walter Reed Army Medical Center
1	CG, Combat Developments Command (CDCMR-V)
1	CG, Quartermaster Res. and Eng. Command
1	Hq., Dugway Proving Ground
3	The Surgeon General (MEDNE)
1	CO, Army Signal Res. and Dev. Laboratories
1	CG, Army Electronic Proving Ground
1	Combat Development Experimentation Center, Fort Ord
1	CG, Engineer Res. and Dev. Laboratory
1	Director, Office of Special Weapons Development
1	CO, Watertown Arsenal
1	CG, Mobility Command
1	CG, Munitions Command
1	CG, Army Missile Command

AIR FORCE

1	Assistant Chief of Staff, Intelligence (AFCIN-3B)
6	CG, Aeronautical Systems Division (ASAPRD-NS)
1	Foreign Technology Division
1	Directorate of Civil Engineering (AFOCE-ES)
1	Director, USAF Project RAND
1	Commandant, School of Aerospace Medicine, Brooks AFB
1	Office of the Surgeon (SUP3.1), Strategic Air Command
1	CG, Special Weapons Center, Kirtland AFB
1	Director, Air University Library, Maxwell AFB
3	Commander, Technical Training Wing, 3415th TTG
1	Commander, Electronic Systems Division (CRZT)

OTHER DOD ACTIVITIES

3	Chief, Defense Atomic Support Agency (Library)

1	Commander, FC/DASA, Sandia Base (FCDV)
1	Commander, FC/DASA, Sandia Base (FCTG5, Library)
1	Commander, FC/DASA, Sandia Base (FCWT)
1	Director of Defense Research and Engineering (OAP)
1	Director, Weapons Systems Evaluation Group
3	Central Intelligence Agency
1	Director, Armed Forces Radiobiology Research Institute

AEC ACTIVITIES AND OTHERS

3	Albuquerque Operations Office
1	Argonne National Laboratory
1	Atomic Energy Commission, Washington
1	Avco Corporation
1	Battelle Memorial Institute
2	Beers, Roland F., Inc.
1	Bridgeport Brass Company
1	Brookhaven National Laboratory
1	Chicago Patent Group
1	Dow Chemical Company, Rocky Flats
2	duPont Company, Aiken
1	Edgerton, Germeshausen and Grier, Inc.
1	Edgerton, Germeshausen and Grier, Inc., Las Vegas
1	General Electric Company, Cincinnati
3	General Electric Company, Richland
1	Hanford Operations Office
1	Holmes and Narver, Inc.
1	Johns Hopkins University (APL)
1	Knolls Atomic Power Laboratory
1	Ling Tempco Vought, Inc.
1	Lockheed Missiles and Space Company
2	Los Alamos Scientific Laboratory
1	Lovelace Foundation
1	Martin-Marietta Corporation, Denver
1	Mound Laboratory
1	NASA Ames Research Center
1	NASA Langley Research Center
1	NASA Lewis Research Center
1	NASA Marshall Space Flight Center
3	NASA Scientific and Technical Information Facility
1	National Lead Company of Ohio
2	Nevada Operations Office
1	New York Operations Office
1	Oak Ridge Operations Office
1	Phillips Petroleum Company (NRTS)
1	Public Health Service

1	Research Analysis Corporation
1	San Francisco Operations Office
1	Sandia Corporation, Albuquerque
1	Sandia Corporation, Livermore
1	Tracerlab, Inc., Richmond
2	Union Carbide Nuclear Company (ORGDP)
4	Union Carbide Nuclear Company (ORNL)
2	University of California, Berkeley
2	University of California, Livermore
1	University of California, Los Angeles
1	University of Washington (APL)
2	Westinghouse Bettis Atomic Power Laboratory
25	Division of Technical Information Extension, Oak Ridge

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Naval Radiological Defense Laboratory
USNRDL-TR-645
GROUND ROUGHNESS EFFECTS FOR FALLOUT-CONTAMINATED TERRAIN: COMPARISON OF MEASUREMENTS AND CALCULATIONS by
J. M. Ferguson 7 May 1963 29 p. table illus.
6 refs. UNCLASSIFIED
The effect of ground roughness on the radiation field above fallout-contaminated ground is studied. At past weapons tests, the dose rate over fallout-contaminated ground has been measured as a function of height
(over)

1. Terrain.
2. Deserts.
3. Dose rate.
4. Radioactive fallout.
5. Radiological contamination.

I. Ferguson, J. M.
II. Title.
III. SF 011 0511

UNCLASSIFIED

and angle. These measurements are compared with calculations of the same quantities for 1.12-hr fission products uniformly distributed on a smooth plane. None of the experiments is detailed enough to lead to firm conclusions about the ground roughness effect. However, the data indicate that the ground roughness effect can be simulated by assuming that the fallout is buried under a thin layer of material. For desert terrain this thickness of material is equivalent to about 25 ± 10 ft of air. At 3 ft above the ground this corresponds to a reduction in dose rate by a factor of 0.6 to 0.7, compared to what would be received over a smooth plane.

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